# Sky in Google Earth: The Next Frontier in Astronomical Data Discovery and Visualization

http://earth.google.com/sky/

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# ABSTRACT

Astronomy began as a visual science, first through careful observations of the sky using either an eyepiece or the naked eye, then on to the preservation of those images with photographic media and finally the digital encoding of that information via CCDs. This last step has enabled astronomy to move into a fully automated era – where data is recorded, analyzed and interpreted often without any direct visual inspection. Sky in Google Earth completes that circle by providing an intuitive visual interface to some of the largest astronomical imaging surveys covering the full sky. By streaming imagery, catalogs, time domain data, and ancillary information directly to a user, Sky can provide the general public as well as professional and amateur astronomers alike with a wealth of information for use in education and research. We provide here a brief introduction to Sky in Google Earth, focusing on its extensible environment, how it may be integrated into the research process and how it can bring astronomical research to a broader community. With an open interface available on Linux, Mac OS X and Windows, applications developed within Sky are accessible not just within the Google framework but through any visual browser that supports the Keyhole Markup Language. We present Sky as the embodiment of a virtual telescope.

Subject headings: Astrophysical Data, Data Analysis and Techniques, Tutorials

#### 1. Introduction

The purpose of this paper is to provide an introduction to Sky in Google Earth<sup>1</sup> – describing the data used in its creation, why certain features appear the way they do and, most importantly, how astronomers can use Sky to create, explore, and share their data with a broad community. We will generally avoid technical details about the underlying mechanisms for serving the imagery and instead focus on the operations required to place

catalogs, images and educational tools within Sky and how to serve these data sets efficiently across the web. This paper should be viewed as a starting point for the reader's interaction with Sky and the beginning of a discussion about what can be accomplished with this new tool.

Astronomical data is deceptively complex. At first glance, it is merely the result of pointing a telescope at the sky and recording what you see. In reality, however, a scientifically useful description of a single observation requires knowledge of when it was taken, from where, over what wavelengths, in what conditions, covering what area, and so on. Combined, the underlying images and associated meta-data provide a data set that is not just esthetically pleasing but is also scientifically meaningful. The goal of Sky is to create a gen-

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eral framework that will enable users to access images, catalogs and any associated meta-data across the full sky in a seamless manner (Szalay & Gray 2001). It will serve optical, infrared, x-rays, ultraviolet and radio images, enable overlays of these images (with transparency), catalogs and ancillary data associated with the underlying images, static, time-varying and transient data. In short, it can deliver a view of the night sky across the full electromagnetic spectrum to a user in an efficient and scalable manner.

### 2. Design

Before discussing how to add your own data to Sky, we begin with a description of the two principal components of Sky: the basemap and the overlays. The first is simply the set of images laid out on the celestial sphere to match their positions on the sky. The second is the collection of lines, placemarks, and images that can be overlaid on the base imagery and the annotations associated with the basic visual data. Below we will describe the contents of both pieces, along with some discussion of the design decisions that went into their development.

#### 2.1. Imagery

The core of Google Earth is a huge RGB color image pyramid projected on a sphere, served via the internet by Google, with client software that runs on each user's computer. This client takes advantage of graphics hardware in their computer to display a window into the huge image database with real time, continuous panning and zooming. Data is stored and served in such a way that redisplay is as smooth as possible, giving the user the illusion that the full detail of all the images is resident locally on their computer when, in fact, only a small portion of it is cached there. Earth was created for imagery of a sphere from the outside, but for Sky we reversed that perspective, using the same infrastructure to serve images of space viewed from inside the celestial sphere.

As with Google Earth, the basemap in *Sky* provides a full-sphere view of the sky by taking images with different resolutions and depths from a range of sources, registering them to a common coordinate system and rendering them as the user's vantage point sweeps across the sky. For

Sky there are three primary imagery sources: the Digitized Sky Survey (DSS; McLean et al. (2000)), the Sloan Digital Sky Survey (SDSS; York et al. (2000)) and images from the Hubble Space Telescope (HST)<sup>2</sup>. The DSS is derived from plate scans of the photographic plates from the Second Palomar Sky Survey (POSSII; Reid et al. (1991)) and the UK Schmidt Southern Sky Survey in the J and F passbands. The digitization of the photographic plates was undertaken by the Space Telescope Science Institute (Lasker et al. 1996) and contains a total of 1788 plates in the Northern and Southern hemispheres. In the north Galactic cap, the DSS images are replaced by data from the Sixth Data Release of the Sloan Digital Sky Survey (SDSS), which covers  $\sim 8000$  square degrees and contains false color images generated from the q, r, and ipassbands. Finally, there are 130 high resolution images drawn from the Hubble Space Telescope which cover some of the most interesting regions on the sky.

The union of these data sets covers the full sky. The underlying imagery used in Sky resides in a lat/long projection (Snyder 1926). This results in substantial distortion at the poles even when re-projecting onto the sphere. Thus, for regions within five degrees of the pole we replace the original images with a lower resolution view of the sky derived from the Tycho II catalog (Høg et al. 2000). These derived images contain stars to a depth of  $B \sim 12$  and each star is represented by a Gaussian, scaled and colored based on the star's magnitude and B-V color.

# 2.2. Data Registration and False Color Images

The underlying projection and registration of images in Sky is based on the technology used in Google Earth. This provides a mature visualization platform on which to develop Sky, a very large user base, a simple but extensible interface and a well-defined and on-going support and development mechanism. It does, however, lead to a small number of trade-offs – related to the way geospatial data is served – that were made in the course of adapting the system to serve astronomical data.

The first of these concerns the bounds used for geodetic coordinates (GEO), which are different

<sup>2</sup>http://www.stsci.edu

from those used in Equatorial coordinates (EQ). The geodetic coordinates range in longitude from -180 degrees West to +180 degrees East. Hence, there is a simple translation that must be made from the latter to the former:

$$RA_{\text{GEO}} = RA_{\text{EQ}} - 180^{\circ}$$
  
 $DEC_{\text{GEO}} = DEC_{\text{EO}}$  (1)

A second issue arises due to the fact that the Earth is an oblate spheroid which will be discussed in §3.4.

All images to be served through Sky were reprojected from their native tangent plane (or gnomic) projections onto the aforementioned lat/long projection. SDSS images were taken from jpeg images in the SDSS archive<sup>3</sup> created as part of the standard SDSS reduction pipeline. The color of the SDSS images was derived from the g, r and i passbands using the color transformation proposed by Lupton et al. (2004). HST press release images were taken from high resolution TIFF images created by the STScI OPO group<sup>4</sup>. For the DSS data, no color images were readily available that matched the color range of the SDSS data. Color images were, therefore, generated from the original FITS format images (allowing for the effects of differential chromatic abberation) in the J and F bands and calibrating the photographic plates such that their stellar locus matched that of the SDSS data. As with Google Earth, the basemap is not static and we anticipate continued improvements as we refine our treatment of the current imagery and new large-scale datasets become available.

#### 2.3. Overlays and Annotation

As mentioned above, the built-in overlays provide a means to annotate the basemap imagery. In its initial release *Sky* utilizes this functionality to provide a simple and intuitive introduction to objects that are visible to the general public and amateur astronomers. For example, we outline the 88 IAU constellations (Figure 1) provide a basic introduction to the morphologies of galaxies visible on the sky and a description of the stages of stellar evolution using examples in the basemap

to illustrate these tours. Likewise, each of the images from the HST is accompanied by a popup balloon containing a snippet of the press release for that image and links for further information. Finally, we have placed icons on objects from the Messier, New General and Yale Bright Star catalogs (Figure 2). These placemarks identify the object, provide basic observational data about the source (names, positions, distance, colors and brightnesses along with links to NED and SIMBAD where appropriate; Figure 3) and, in some cases, include a snippet from Wikipedia about what is known about that star, star cluster, nebula or galaxy.

In addition to these static layers, we also provide a time-based layer which shows the position of the Moon and Solar System planets over the course of three months' time. The ephemeris data was generated using the JPL Horizons interface<sup>5</sup>. The associated placemarks indicate the distance, magnitude and angular extent of each body as a function of time, controlled by a slider bar that appears in the upper right corner of the window when these layers are activated. It is worth noting that planets' and the Moon's icons are not scaled according to their actual appearance on the sky so that they can be more easily distinguished from the background stars. The duration of the time interval is sufficient to show both prograde and retrograde motion in the planetary orbits.

#### 3. Adding Data to Sky

While the basemap provides a common reference frame and a view of the optical sky, the strength of Sky comes from its ability to incorporate and display user generated data (images, catalogs, time variable data, tours of the sky) on top of the basemap. This wide array of functionality is one the advantages of a mature platform, as Earth has been performing similar tasks for the GIS community for a number of years. For example, the x-ray flux from a galaxy cluster can be displayed on top of the optical galaxies seen in the basemap, which can themselves be tagged with placemarks containing the survey data for each of the member galaxies. Likewise, infrared, ultraviolet and radio imaging of a single galaxy can be overlaid simultaneously, with the user in complete

 $<sup>^3</sup>$ http://www.sdss.org/dr6/data/das\_users\_guide\_dr2

<sup>4</sup>http://hubblesite.org

<sup>&</sup>lt;sup>5</sup>http://ssd.jpl.nasa.gov/?horizons

control of the transparency of each layer. In this section, we will discuss the basic tools available for incorporating data within Sky, as well as point to some examples currently available for download to supplement the basic Sky package.

#### 3.1. Keyhole Markup Language

Most of the methods for putting data into Sky involve some use of Keyhole Markup Language (KML). An introduction to the KML schema can be found at the Google API documentation site<sup>6</sup>. Like HyperText Markup Language (HTML) and XML, KML files are composed of tags and attributes. Each tag describes an entity (such as the coordinates for a point on the sky or the bounding box for an image) and each attribute defines parameters associated with that entity. KML files can be used to add catalog data with placemarks, imagery with overlays, and vector data in the form of lines and polygons. As with HTML, the basic building blocks can be combined in a variety of ways to create data sets as utilitarian or richly formatted as the user desires. The KML standard also evolves over time, adding features and interfaces based on user feedback and proposed usage cases.

#### 3.2. Placemarks

The most basic element for displaying data is the placemark. This acts as a single push-pin located at a discrete point on the sky, possibly with some associated data; indeed, the default icon for a placemark is an image of a push-pin. KML allows users to customize the icon associated with a placemark, as well as the information that appears in the pop-up balloon when a user clicks on the placemark. More advanced features include the ability to control when the placemark appears and how the camera moves when the user clicks on the placemark. For example, the appearance of the default catalog data in Sky is tuned to the objects' magnitudes. This keeps fainter objects from appearing until the user is at a higher zoom level, which avoids having the viewer overwhelmed by a unmanageable number of placemarks on the sky at any given time. Likewise, visibility of placemarks can be governed by the region of the sky shown in the viewport at any given time, preventing multiple catalogs across the full sky from being rendered at the same time and improving the efficiency of serving the data.

#### 3.3. Vector Data

The next stage of sophistication is vector data: lines and polygons. These are essentially collections of placemarks, with line segments connecting them and (in the latter case) a solid color filling the enclosed area. In both cases, users can control both the color and transparency of the lines and polygons. This makes vector data ideal for a quick description of a observational footprint or uncertainty region associated with a survey or observation, as one might have with the observation of a gamma ray burst, for example.

#### 3.4. Image Overlays

The KML tag name GroundOverlay is inherited from Earth, but these are simply images projected against the basemap in Sky. GroundOverlays are defined by associating an image with some bounding region on the sky, the latter being given by the bounds in the four cardinal directions and a rotation angle. For small-area images, the difference between the tangent plane and lat/long projection is slight enough that images can be aligned to the basemap using only a linear transformation. Google Earth has a graphical interface for aligning images this

Larger images (or those nearer the poles) can be more difficult. As mentioned previously, since Sky shares a rendering engine with Earth, the geometry of the sky is, in fact, a slightly oblate spheroid (technically, the WGS84 projection). The GIS community has developed a number of tools for handling re-projections of images using this geometry, most notably the Geospatial Data Abstraction Library (GDAL). This software can warp images from one projection (including a tangent plane) to another and encodes the geometric information necessary for registering the image on the sphere in either an image header (analogous to a FITS header) or an associated "world file", depending on the image format. While users may want to become more familiar with the GDAL software themselves, we provide a simple, open

<sup>6</sup>http://code.google.com/apis/kml/documentation/

source tool  $wcs2kml^7$  which will read in an image in a variety of formats and WCS information from a FITS header and generate a properly warped image and overlay KML for you. This tool is available in both Python and C++ versions.

#### 3.5. Network Links and Regionation

While the basic elements of KML are static, network links allow users to load new KML dynamically. This may be triggered by a change in the view of the camera in *Sky* or after a specified interval has elapsed. This flexibility allows for a limitless number of applications: updating the location of satellites in orbit or their current observing target, displaying feeds from gamma ray burst trackers, providing real-time updating of observations to collaborators back home, and so on. Likewise, the ability to have network links activated based on the viewport of the sky gives KML authors the ability to regionate their data.

Regionation is simply splitting a given data set into a hierarchical structure, similar to what happens with the imagery and placemarks that are part of the basic Sky data set. When the camera is far from the surface of the celestial sphere, the imagery served is at a very low resolution (finer details would be lost anyway, so displaying them is unnecessary) and only the brightest stars and galaxies are annotated to avoid overwhelming the user. As the camera zooms in, higher resolution imagery is fetched automatically and fainter objects are tagged. The same can be accomplished with network links to other files that are tied to progressively smaller regions on the sky. This allows vast amounts of catalog data and high resolution imagery to be displayed progressively on demand, instead of clogging the user's internet connection all at once. Regionator<sup>8</sup>, an open source Python program, provides a simple interface for regionating KML files that have already been created (like those produced by the Python version of wcs2kml, for example). The C++ version of wcs2kml includes a feature which will regionate its outputs as well, producing a hierarchical set of network linked KML files and sub-sampled versions of astronomical images with associated WCS information. For large mosaics (or even images taken with large format CCDs), this can vastly improve the performance of the resulting image overlay. The *wcs2kml* package also includes utilities for converting FITS catalog data to KML placemarks and regionating them as well.

#### 3.6. Sharing & Publishing Data

Since KML is completely platform independent, data sharing is easy. Simply construct a KML file describing your data and email it to your collaborator. Even better, place it on a webpage where it can be discovered and shared with the world. Larger KML files (which are fundamentally just simple ASCII text files) can be compressed into a zip archive (generally tagged with a ".kmz" suffix to differentiate them from uncompressed files) along with imagery to form a self-contained file that can be opened natively by Sky. Alternatively, imagery can be loaded with URL pointers, just like in standard HTML.

#### 3.7. Working with KML in Sky mode

KML was created to annotate Google Earth with images, placemarks and ancillary information. As the KML schema is designed to support this Earth-centric annotation some of the features and tags present within KML do not translate naturally to annotation of the sky. We provide here a brief overview of these tags and features and provide workarounds for their use in *Sky*.

To differentiate between KML for viewing on the *Sky* as opposed to on *Earth* a hint attribute is available within the initial specification of the KML schema. Adding the *Sky* hint<sup>9</sup> to your <kml> tag will cause the client to prompt a user to open the KML under sky mode (if the view is currently *Earth*-based). All KML saved from within the Google Earth client while it is in *Sky* mode will have this attribute set by default.

Placemarks, image overlays, lines, polygons and styles are all supported under *Sky*. Tilt and roll angle for the camera position are ignored when viewing images and placemarks under *Sky* as the current astronomical imagery is a simple projection onto a sphere without altitudinal information. Range for the LookAt and other positional tags

<sup>7</sup>http://code.google.com/p/wcs2kml/

<sup>8</sup>http://code.google.com/p/regionator/

<sup>9&</sup>lt;kml xmlns="http://earth.google.com/kml/2.2" hint="target=sky">

(i.e. the altitude above the Earth that the camera zooms to when a placemark is double-clicked) are measured in meters. To convert to an angular system that is more appropriate for viewing the sky we suggest the following relation,

$$R\sin(\alpha/2 - \beta/2) = (R - r)\sin(\alpha/2) \qquad (2)$$

where r is the range to use in the LookAt tag, R is the radius of the Earth (6371 km),  $\alpha$  is the angle subtended by the viewer when you are viewing from the maximum distance from the sky (i.e. you are pulled all the way back to the center of the Earth; for the current client  $\alpha = 80^{\circ}$ ) and  $\beta$  is the angular diameter of your region. For  $r \ll R$ , this reduces to,

$$\beta = 2r \tan(\alpha/2)/R \tag{3}$$

where  $\beta$  is in radians.

Images that are incorporated into Sky are correctly oriented (i.e. East to the left) and do not require any transformations other than rotation. Rotation in Sky is in the clockwise direction (opposite from that in Earth mode). 3D sketchup models for objects within Sky are not officially supported but may work.

## 4. Future

The research applications of Sky are limitless. Data can be visualized from an all-sky view all the way to native resolution of the underlying imagery with minimal pre-processing. Catalog data can be immediately placed on the sky imagery with KML placemarks enabling new discoveries to be made available in almost real time. Data can be shared within a research group or to the broader community securely by simply sending KML files or posting them on a webserver. Finding charts are as simple to create as producing a screenshot or zooming to a location just prior to observing. Survey progress can be visualized in real time by updating KML available over the internet (via network links) as images come off the CCDs. Finally, when the observations are ready to be made public, Sky is an ideal platform to reach parts of the general public interested in astronomy and put your results in the context of the broader astrophysical data universe.

As a tool with a simple, extensible and intuitive interface we see Sky in Google Earth as the embod-

iment of a Virtual Telescope, providing open access to data through open standards. It leverages the power of the Google infrastructure for serving data to a wide range of people while also enabling any user to integrate and share their own images and catalogs. We hope that this step towards the democratization of science will enable a new era of visual discovery and science communication.

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Please see the Sky partners homepage<sup>10</sup> for a list of the institutions contributing imagery to Sky.

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<sup>10</sup>http://earth.google.com/sky/partners.html

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This 2-column preprint was prepared with the AAS IATEX macros v5.2.

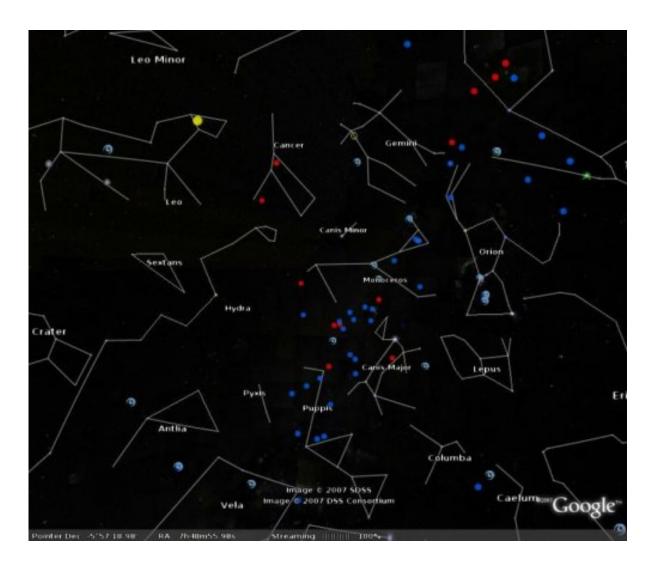


Fig. 1.— Large scale image of the sky showing constellations and Messier (red) and NGC (blue) object tags. The basemap imagery is largely dark thanks to the re-sampling of the DSS and SDSS imagery to lower resolution, although a number of stars are visible at the junctions of the constellation lines. Icons are also available for objects in the Yale Bright Star catalog, although they are deactivated in the current image.

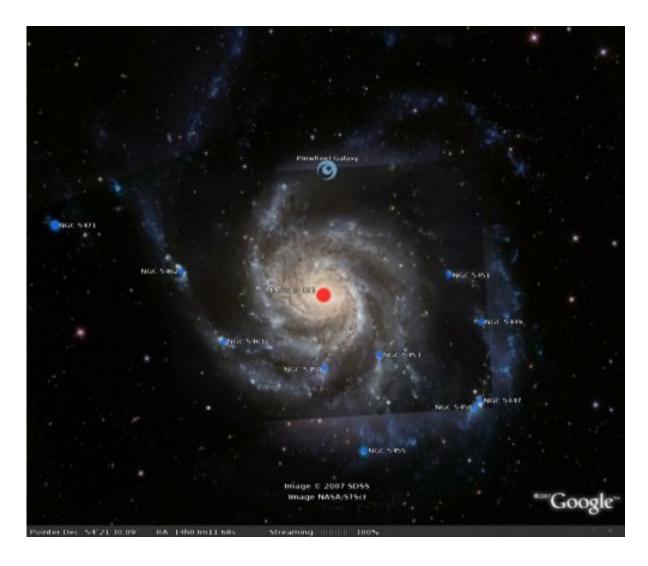


Fig. 2.— Closer view of the imagery for the area of sky around M101. As the credits at the lower middle of the image indicate, this imagery is a combination of data from the SDSS and the HST, with the latter providing a higher resolution mosaic of the central galaxy region. The icon at the top of the M101 HST imagery contains information related to the press release issued by the STScI for this image, as well as links to associated papers and observational data.

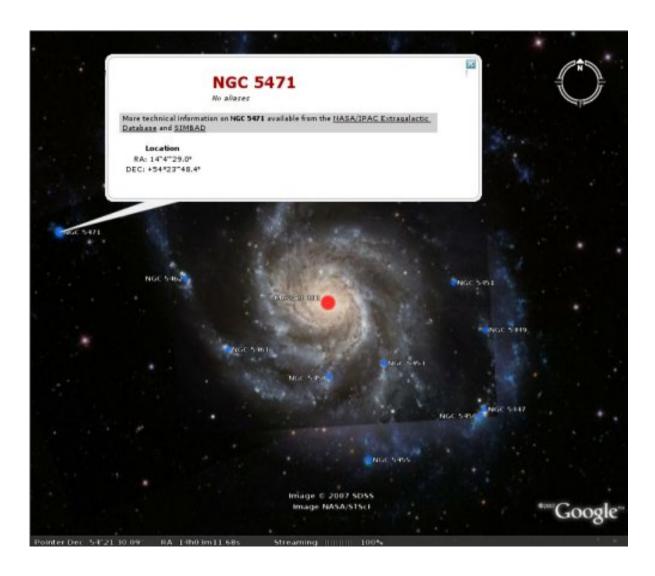


Fig. 3.— Same as Figure 2, but with the information balloon for one of the NGC objects opened. These balloons contain basic observational data as well as links to the NED and Simbad databases for further information and a snippet of Wikipedia text for each object, if available. This particular balloon, chosen so as not to obscure the imagery, shows the bare minimum of information available for a given object.